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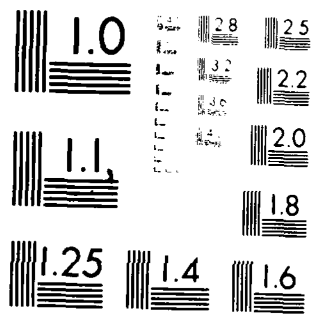

MICROCOPY RESOLUTION TEST CHART

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LIFE CYCLE ANALYSIS PROCEDURES AND TECHNIQUES: AN APPRAISAL AND SUGGESTIONS FOR FUTURE RESEARCH

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P-6031

LIFE CYCLE ANALYSIS PROCEDURES AND TECHNIQUES: AN APPRAISAL AND SUGGESTIONS FOR FUTURE RESEARCH*

CHART 1

This briefing presents some observations about the procedures and techniques used in life cycle cost analyses. "Procedures" is used here to denote the manner in which analyses are performed and results presented to decisionmaker. "Techniques" refers primarily to the cost models and other tools used to make cost estimates.

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*This paper was presented at the Twelfth Annual Department of Defense Cost Analysis Symposium, Colorado Springs, Colorado, October 1977.

Chart 1

LIFE CYCLE ANALYSIS PROCEDURES AND TECHNIQUES: AN APPRAISAL AND SUGGESTIONS FOR FUTURE RESEARCH

CHART 2

At the request of the Air Force Deputy Chief of Staff for Research and Development, Rand has been studying the application of life cycle analysis to the evaluation of proposed investments of R&D and procurement funds. The primary focus of this study has been on aircraft systems and on decisions involving program changes and modifications to systems already in acquisition. DSARC-level, major weapon system "go ahead" decisions have been given relatively scant attention in this study. The subject decisions are, however, above the level of daily program management decisions and often involve substantial commitments of acquisition dollars.* Examples include the choice between installation of sophisticated avionics for aircraft navigation and use of navigator (with less costly avionics), and selection of a design for subsystem hardware (radars, diagnostic equipment, etc.).

The major characteristic of these kinds of investment decisions is that they are made with the expectation of some sort of tangible payoff--usually in the form of downstream operations and support (O&S) cost savings, hence a reduction in overall life cycle cost. Even in cases where the principal purpose of the investment is an improvement in the capability, performance, or readiness of the weapon system, there is usually concern that this payoff be achieved at a modest penalty in projected O&S cost. The common thread is that some potential--and favorable--life cycle cost and/or performance impact is involved.

In carrying out this study, our perspective has been that of a headquarters-level R&D decisionmaker--the manager at the end of the review process who must evaluate a system proposal supported by a life cycle cost analysis and make the decision about investing acquisition funds. From that perspective, it is evident that the

*Despite this somewhat limited focus, the research included some study of investment decisions in the other military departments and major system acquisition decisions as well. Hence, we feel that the observations presented here apply to a more general class of problems than those providing the initial focus of the research.

Chart 2

CONTEXT: EVALUATION OF INVESTMENT OPPORTUNITIES

- DECISIONS BELOW THE DSARC LEVEL
- INVESTMENT OF R AND D DOLLARS WITH PAYOFF IN
  - O AND S COST SAVINGS
  - IMPROVED PERFORMANCE-READINESS
- PROBLEM: ANALYSES INADEQUATE FOR DECISIONMAKING
  - CONFLICTING ESTIMATES
  - INCONSISTENT PROCEDURES
  - RISK OF INCORRECT DECISIONS

"typical" life cycle analysis is simply inadequate as a basis for reaching a sound resource allocation decision. This inadequacy results in part from the widely differing cost and performance estimates--purportedly generated for the same proposal--that come from different analysts and different organizations. It also results from the tendency for each analysis to be prepared and presented in a different way. To the decisionmaker, there appears to be no common set of rules and procedures, and each analysis that he sees presents a new puzzle to be solved.

The ultimate risk in this situation is that incorrect decisions will be made--incorrect in the sense that the sought-after least-cost system may not be the one selected by the decisionmaker. Confusion as to the meaning of a cost estimate could lead to missed opportunities to achieve real cost reduction, or worse yet, to unintended cost increases resulting when acquisition funds are spent for "savings" that cannot be realized as "hard" dollars.

The observations presented here are intended to deal with the causes of these problems and some potential solutions. No attempt has been made to identify the beneficial aspects of current life cycle cost analysis practice (which, of course, are present along with the detrimental ones); rather, the emphasis is on areas where improvements can be made. If we, the analytical community, can reach a common understanding of these problems, we will then be able to work on increasing the usefulness of life cycle analysis as an acquisition decision tool.

CHART 3

Our study has had two main elements. The first consisted of case studies, primarily studies of proposed program changes for equipment used on Air Force aircraft weapon systems. We examined the procedures used in these studies and the cost estimating techniques selected. In a few cases we attempted to reproduce the cost estimates, to ensure that we understood the problems involved.

We simultaneously undertook an examination of a number of cost models often used on Air Force programs. At least two of them, the Logistic Support Cost Model developed by AFLC and the CACE cost factors model, have been required for use in a number of acquisition programs. We also examined some logistics planning models sometimes used in life cycle analyses to obtain a disaggregated view of logistics functions. These include the Logistics Composite Model (LCOM), which is most often applied to maintenance manpower estimation, and MOD-METRIC, a spares inventory requirements model.

Although the detailed case studies were Air Force programs, and the models we evaluated were mostly Air Force models, we believe our findings to be valid for the other services as well. Our case studies included enough non-Air Force programs to convince us of the generality of our conclusions.

Chart 3

APPROACH

- CASE STUDIES
- EVALUATION OF MODELS

CHART 4

Our examination of the case studies uncovered a number of problems that could easily confuse a decisionmaker. Three problems related to the selection and treatment of cost elements are shown in this chart. One problem is that effects which are inherently different are often combined into a total cost figure which, because of the different natures of its components, is difficult to interpret or evaluate.

A decisionmaker concerned about getting the most return on the service's investment dollars is especially interested in savings (and costs) that represent changes in required budget levels. Many studies include in the estimate of total cost both budget dollars and non-budget "values" (expressed in dollar terms) for other types of benefits such as changes in weapon system capability or changes in resource utilization. A reliability improvement might, for example, generate real reductions in demands for maintenance manhours, but there will be no resulting decrease in the budget unless the manhours can be translated into a reduction in manpower. This translation requires that the cost model, in addition to dealing with direct maintenance manhours, account also for other causative agents or driving factors that affect maintenance manpower.

Chart 4

PROBLEMS OBSERVED IN CASE STUDIES - I

- AGGREGATIONS OF DISSIMILAR EFFECTS
  - COST
    - BUDGET DOLLARS
    - RESOURCE DEMANDS
  - CAPABILITY
- SIGNIFICANT COSTS OMITTED OR LIGHTLY TREATED
- INCONSISTENT COST ELEMENT STRUCTURES

CHART 5

Estimating maintenance manpower requirements is much more complex than estimating manhours. Many factors are involved, only a few of which are weapon system related. The interaction of these factors produces a variation of manpower (and therefore maintenance cost) with workload that is highly nonlinear. The actual dollar cost of maintenance labor can seldom be accurately estimated by applying a cost per hour to a maintenance manhour estimate, but this is frequently done. If such a cost is added to budget dollars, the result is a total whose significance is difficult to interpret.

MAINTENANCE MANNING ESTIMATION

FUNCTION

- WORKLOAD
  - INSPECTION
  - SERVICING
  - UNSCHEDULED MAINT.
- MINIMUM MANNING LEVEL

DRIVING FACTORS

- OPERATION SCHEDULE
- PHYSICAL ENVIRONMENT
- EQUIPMENT I & S CHARACTERISTICS
- EQUIPMENT R & M CHARACTERISTICS
- MAINTENANCE ORGANIZATION
- TRAINING POLICY
- OPERATIONS AND ALERT SCHEDULE

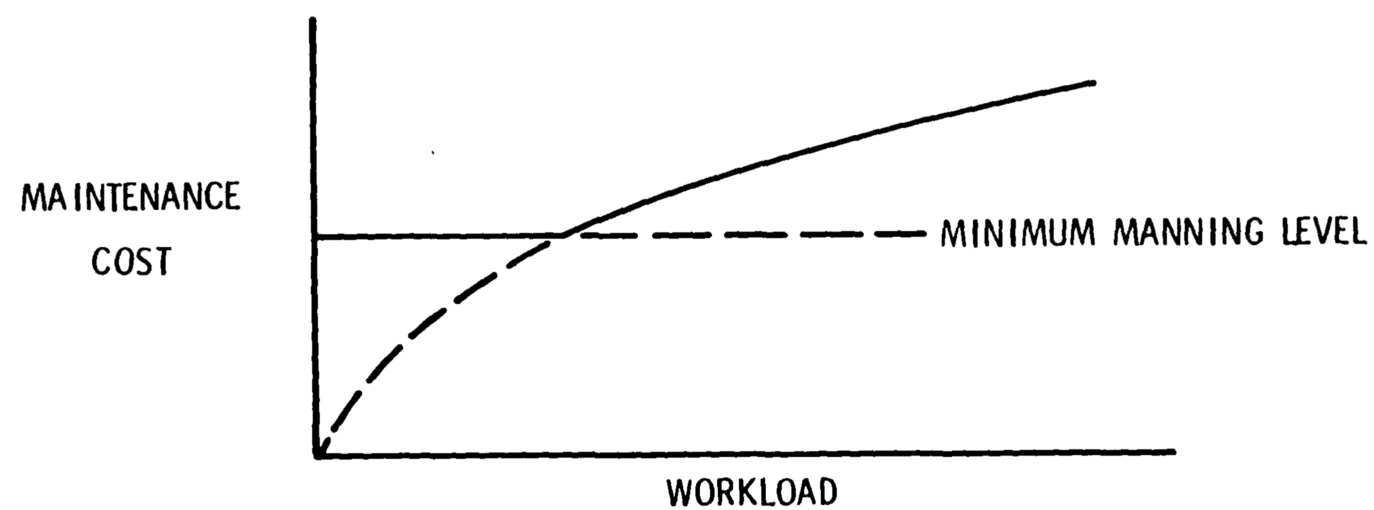

Chart 5

CHART 6

The situation for capability changes is similar. Improved aircraft availability, such as that which sometimes results from a reliability increase, can be used to generate additional sorties. We have seen the value of these sorties translated into dollars, often through some connection to the procurement cost of the aircraft. Such a dollar figure is almost always a poor measure of the actual military value of the additional available hours. To add such a figure to a real budget dollar cost is to obscure the significance of the two different types of effects.

Another problem is the lack of sufficient depth of analysis of significant elements of cost. One case study estimated development, flyaway, and recurring O&S costs of the subject hardware; but omitted the initial support investment cost, including initial spares and support equipment. The same study estimated annual O&S cost as a percent of flyaway cost, although the life cycle O&S cost was the largest single cost in the analysis. The total cost result could probably have been significantly more accurate if the O&S costs had been generated with greater sensitivity to the reliability, maintainability, and physical features of the hardware.

One reason these problems exist is that there is no standard cost element structure that an analyst can use as a guide--a comprehensive list from which to select the elements significant in a particular case. Use of a standard set of elements would also facilitate comparison of one investment opportunity with another.

Chart 6

PROBLEMS OBSERVED IN CASE STUDIES - I

- AGGREGATIONS OF DISSIMILAR EFFECTS
  - COST
    - BUDGET DOLLARS
    - RESOURCE DEMANDS
  - CAPABILITY
- SIGNIFICANT COSTS OMITTED OR LIGHTLY TREATED
- INCONSISTENT COST ELEMENT STRUCTURES

CHART 7

Other problems in the case studies are less closely related to the individual cost categories. One is the problem of poorly selected or poorly defined baselines against which to measure the cost impact of alternative cases. In concept, there are at least two important baselines, representing somewhat different estimates of costs that will be incurred if the decisionmaker elects not to make a proposed investment. The program baseline is the officially recognized cost estimate contained in financial planning documents. The other baseline is the analyst's best estimate of the cost of the planned system. This can differ from the program baseline because of the use of more recent information or more detailed estimating techniques. Both the program baseline and the best estimate are important for comparison and for implementation of the decision, but they are meaningful only so long as they are kept separate. This separation is not always maintained in analyses. In one of our case studies, for example, the cost of spares for the proposed system was compared with the spares cost taken from the programmed baseline, but the depot maintenance cost of the new equipment was compared with the analyst's best estimate of the depot maintenance cost of the current equipment. A total cost change computed by summing incremental effects such as these can have little real meaning for the decisionmaker.

A decisionmaker can be expected to want to know how much uncertainty is associated with the cost estimates he receives and how sensitive they are to changes in other variables that are themselves uncertain. One of the case studies reviewed in detail included a sensitivity study, but this is the exception rather than the rule.

One problem that relates directly to decisionmakers' confusion over inadequate cost estimates is a dearth of interpretive material in the presentation of results. The weaker the procedures and estimating techniques used in a particular analysis, the more help the decisionmaker needs in evaluating the results. If some resource reductions are readily converted into budget dollars and others are not, this should be made explicit. Any actions on the part of management

Chart 7

PROBLEMS OBSERVED IN CASE STUDIES - II

- ILL-DEFINED BASELINES
- UNCERTAINTY-SENSITIVITY NOT ADDRESSED
- LITTLE INTERPRETATION OF RESULTS
  - MANAGEMENT ACTIONS REQUIRED
  - STRENGTHS AND WEAKNESSES OF ESTIMATING TOOLS
  - LIKELIHOOD OF ACHIEVING PREDICTED SAVINGS

that are necessary to achieve a budget impact should also be pointed out. Often an investment in new hardware will create an opportunity to save cost, but the potential savings can become real only if, for example, the maintenance concept is changed to accommodate the improved characteristics of the new equipment. The strengths and weaknesses of the models and data used are not usually made explicit. This is a problem regardless of whether the estimate is based mainly on generalized models or on specialized models and data samples collected especially for a specific study.

Some estimated savings are more readily achieved than others. As noted above, not all changes in weapon system resource requirements automatically result in cost changes. Also, many costs normally included in system LCC are driven only slightly, if at all, by the weapon system itself. Base operating support and health care are examples of costs that are assigned by convention to weapon systems, but which have only limited sensitivity to weapon system characteristics. A decisionmaker needs to know how much of a total predicted cost or savings he can expect to be easily achieved and how much is not really a weapon system-driven cost.

These various problems are all potential sources of confusion for a decisionmaker. They occur frequently enough to be significant and to point out the need to develop improved procedures. The key point here is that, from the point of view of the R&D decisionmaker, the life cycle cost estimates prepared under current procedures present a very mixed picture. His problem is to make decisions involving the allocation of scarce acquisition dollars, but the cost estimate he sees may include hidden "value" estimates, uncertainties, and other "cost" figures that may not be at all comparable to the real dollars he is asked to spend. Hence he finds it difficult both to evaluate an individual proposal and to compare proposals that compete for the same funds.

CHART 8

The second phase of our research was the evaluation of cost models. The selected models represent the state of the art in generalized LCC estimating. Some cost studies use ad hoc estimating methods, but most studies rely on the use of "standard" cost models for at least part of their methodology. We are interested in the ability of the models to represent the real-world relationships between weapon system changes and the elements of LCC. We defined a set of what we termed "cost driving factors"--categories of parameters that can be expected to vary as a result of the investment decisions we are concerned with. These driving factors include the characteristics of the weapon system itself and the functions and policies of operations and support concepts. We used a cost element structure based on that published in the Logistics Management Institute draft of the CAIG "Cost Development Guide for Aircraft Systems",* modified slightly so that the cost element definitions were compatible with the Air Force budget categories.

We considered each driving factor-cost element combination separately to see if the models were able to provide useful sensitivity to the real cause-effect relationships. A matrix format was selected for display of the results.

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*Norman E. Betaque, Jr., and Marco R. Fiorello, Aircraft System Operating and Support Costs: Guidelines for Analysis, Logistics Management Institute, March 1977.

Chart 8

EVALUATION OF ESTIMATING MODELS

COST DRIVING FACTORS → COST MODELS → LIFE CYCLE COST

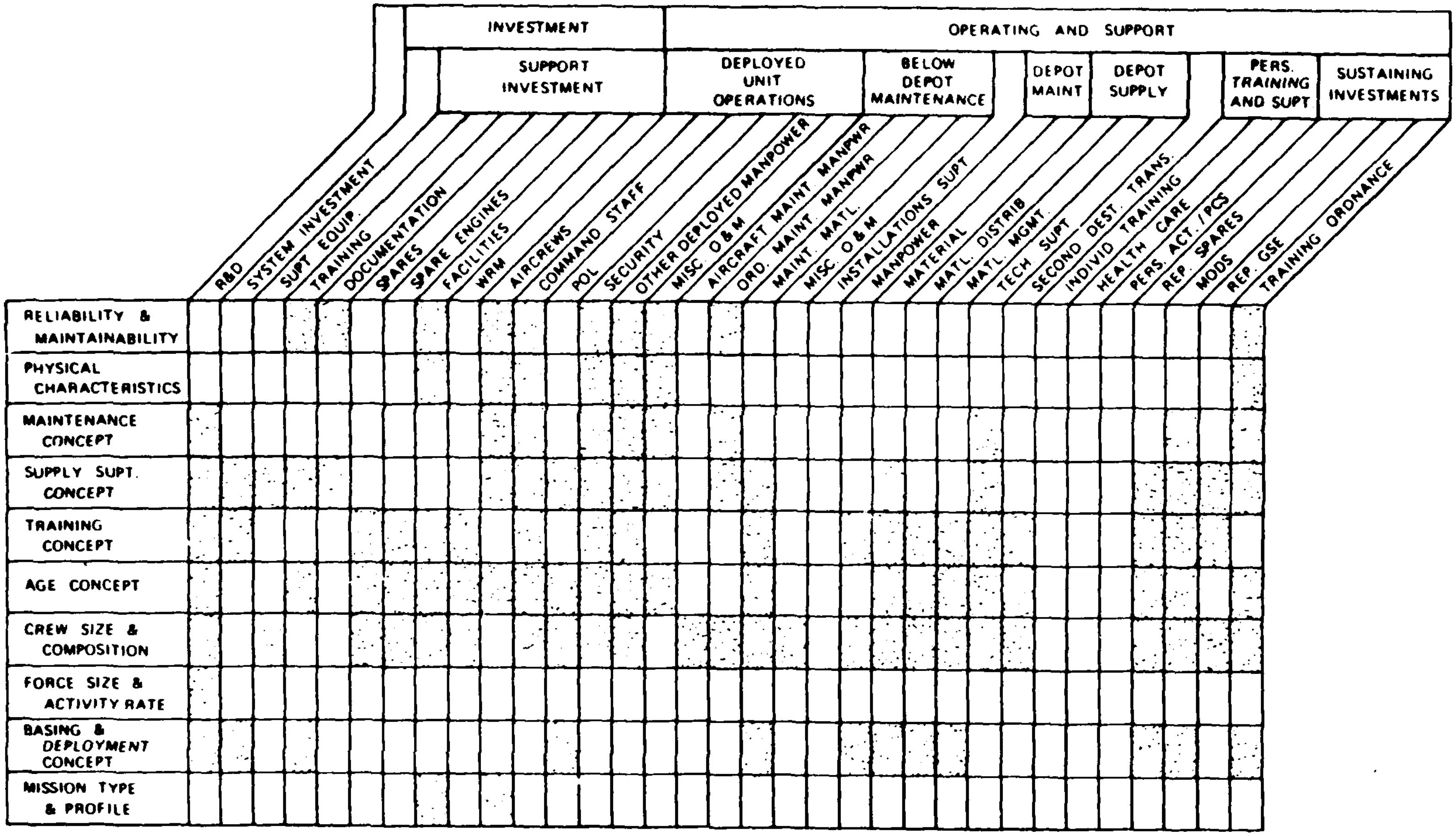
INPUT	OUTPUT
WEAPON SYSTEM CHARACTERISTICS	RESEARCH AND DEVELOPMENT
SUPPORT CONCEPT	INVESTMENT
OPERATIONS CONCEPT	OPERATIONS AND SUPPORT

CHART 9

The blocks shaded gray in this chart correspond to driving-factor/cost-element pairs that we expect to be unrelated. For example, aircraft reliability and maintainability are not expected to affect the cost of training ordinance. Every open block in this chart represents a relationship that we would like the models to be able to account for. Each model was evaluated individually in terms of how well it covered each of these open blocks. Combining the separate model evaluations gives a judgment of the overall adequacy of generalized LCC models.

Chart 9

MODEL EVALUATION MATRIX



Black-shading = No relationship

CHART 10

The letters in the various blocks of the matrix shown in this chart represent our judgment of the extent to which the models, taken collectively, represent the cause-effect relationships associated with individual blocks. A "G" (good) indicates that the models provide an adequate degree of useful coverage. "F", for fair coverage, is used when the models have some useful sensitivity but do not fully address the real-world relationship. A "P" means poor coverage is provided. This is used in cases in which one or more of the models addresses the relationship, but in a way that is misleading or has an unknown or obscure connection with the content of the cost element. If the models do not address a relationship at all, an "N" is placed in the corresponding block of the matrix.

Consider as an example the effect of reliability and maintainability (R&M) on Aircraft Maintenance Manpower, an element of Below Depot Maintenance cost. The aircraft maintenance workload is driven in part by aircraft component failure rates and required repair times and team sizes. The Logistics Support Cost model provides some sensitivity to these parameters, but it bases costs on manhours rather than manpower and does not address manpower needed for repair of shop replaceable units. The Logistics Composite model does relate component R&M characteristics to manpower, but only for conventional maintenance concepts. Both of these models provide partial coverage of the relevant relationships, but neither is complete. It is not feasible to combine them in a way that will provide complete coverage, so the overall coverage is only rated fair.

The criterion of evaluation applied here--the ability of the models to represent the relevant cause-effect relationships--is a somewhat demanding one. But the examination of case studies indicated that for many types of investment proposals that criterion was an important one, because cost savings estimates produced by LCC models were used as an important measure of the value of the proposals. On the whole the small number of blocks in the chart with "good" coverage indicates that the available models are generally inadequate by this criterion. There is no single cost element for which all

Chart 10

OVERALL COVERAGE OF THE COST MODELS

		INVESTMENT								OPERATING AND SUPPORT																							
			SUPPORT INVESTMENT							DEPLOYED UNIT OPERATIONS						BELOW DEPOT MAINTENANCE					DEPOT MAINT		DEPOT SUPPLY				PERS TRAINING AND SUPT			SUSTAINING INVESTMENTS			
	R&D	SYSTEM INVESTMENT	SUPT EQUIP	TRAINING	DOCUMENTATION	SPARES	SPARE ENGINES	FACILITIES	WRM	AIRCREWS	COMMAND STAFF	POL	SECURITY	OTHER DEPLOYED MANPOWER	MISC O & M	AIRCRAFT MAINT MANPWR	ORD. MAINT MANPWR	MAINT MATL	MISC O & M	INSTALLATIONS SUPT	MANPOWER	MATERIAL	MATL DISTRIB	MATL MGMT	TECH SUPT	SECOND DEST TRANS	INDIVID TRAINING	HEALTH CARE	PERS ACT / PCS	REP SPARES	MODS	REP GSE	TRAINING ORDNANCE
RELIABILITY & MAINTAINABILITY	F	F	F			F	G		F			N				F		P	N	P	F	P	F	N	N	F	P	N	N	F	P	N	
PHYSICAL CHARACTERISTICS	F	F	N	N	N	F	G		F			F				F	F	P	N	P	P	P	F	F	N	F	P	N	N	P	P	N	
MAINTENANCE CONCEPT		N	F	P	N	P	F	N	P			N				P		P	N	P	P	P	P	N		P	P	N	N	P		N	
SUPPLY SUPT CONCEPT						F	F	N	P							F			N	N	N		N	N		N	N	N	N				
TRAINING CONCEPT			N	N	N					N		N			N	P	N		N	N							P	N	N				N
AGE CONCEPT		N	F		N											F	F		N	N	N						P	N	N			N	
CREW SIZE & COMPOSITION		N		N	N					G					P					F							F	F	F				
FORCE SIZE & ACTIVITY RATE		F	F	N	N	F	G	N	F	G	F	F	F	F	P	F	F	F	P	F	F	F	F	N	N	F	F	F	F	F	F	F	F
BASING & DEPLOYMENT CONCEPT			F		N	F	F	P	F	N	F		N	F	N	F	F		N	N					N	F	N	N	N			N	
MISSION TYPE & PROFILE	F	F	N	N	N	N	N		N		F	F	N	N	N	F	F	N	N	N	P	P	N	N	N	N	N	N	N	N	P	N	F

Key:

G = good
F = fair
P = poor
N = none
Black shading = no relationship

potential cost drivers can be addressed satisfactorily. Thus, for most problems it may not be possible to generate a completely satisfactory cost estimate for generalized models alone. Until better models can be developed, the prediction of the real cost changes associated with R&D investments will be dependent on the analyst's ability to supplement models with additional analysis and with an interpretation of study results.

Based on these results for the models and on the procedural problems identified earlier, it is possible to formulate some suggestions for ways in which LCC estimates might be improved.

CHART 11

Near term goals could relate to making better use of existing estimating techniques. A consistent set of standards and procedures for proper LCA is needed. We can improve the situation somewhat by striving individually for better analysis, but greater improvement would result from our joining forces to develop a single set of procedures applicable to the widest practical range of decisions.

Two specific items we would propose as elements of such standard procedures are a standard cost element structure and the use of a greater amount of interpretive material. Standard cost elements would reduce the likelihood of omitting potentially important cost elements and would facilitate comparison of investment opportunities. The limitations of current models and data sources make it especially important that the analyst also assist the decisionmaker by making the implications of study results explicit.

Chart 11

GOALS FOR IMPROVED LCC ESTIMATES

NEAR TERM --
BETTER USE OF EXISTING METHODOLOGIES

- CONSISTENT STANDARDS AND PROCEDURES
- STANDARD COST ELEMENT FRAMEWORK
- CRITICAL INTERPRETATION OF RESULTS

CHART 12

Over the long term, significant improvements in the cost models can be achieved. Basing next-generation models on a standard cost element structure would help insure that all cost impacts are identified. The standard elements should also be defined to be compatible with categories used in the budget. This compatibility is needed so that we can generate cost estimates and trace real costs in the same terms, providing a means of validating the models and facilitating the conversion of system cost estimates into changes in the budget.

More accurate representation of real cause-effect relationships is needed. The modeling of costs driven directly by the weapon system could be extended to provide sensitivity not only to hardware characteristics but also to the functions and policies of operations and support. Maintenance costs estimates, for example, could be improved by accounting for all scheduled maintenance, servicing, and general support tasks instead of concentrating only on repair actions. Costs that are not directly related to individual weapon systems, but which are by convention included in system LCC, should be estimated with more sensitivity to the mechanisms that set budget levels and to forcewide policies that are accounted for in those budgeting processes. The effects of basing structure and the organization of the training establishment both impact LCC, but they are not the direct result of weapon system decisions.

The full implications of a LCC estimate cannot be understood without some measure of weapon system output, such as maximum achievable sortie rate. There are often tradeoffs that can be made, within the scope of a single decision, between LCC and system output. One of the case studies we examined credited some new equipment with the ability to reduce the number of spare engines needed to support a weapon system. That study computed a resulting cost reduction by multiplying the reduction in the number of engines by engine unit procurement cost. Another possibility--one not addressed by the initial analysis--would be to buy the originally-planned number of

Chart 12

GOALS FOR IMPROVED LCC ESTIMATES

LONG TERM -- COST MODEL IMPROVEMENTS

- STANDARD COST ELEMENT STRUCTURE
  - COMPLETE LCC COVERAGE
  - COMPATIBLE WITH BUDGET-FYDP CATEGORIES

- REAL CAUSE-EFFECT RELATIONSHIP
  - DIRECT: HARDWARE, O AND S FUNCTIONS AND POLICIES
  - INDIRECT: BUDGET MECHANISMS, FORCEWIDE POLICIES

- WEAPON SYSTEM OUTPUT

engines, and take the "benefit" in increased engine availability. This could translate into increased availability of aircraft for flight operations or into an increased sortie rate. Such opportunities should be identified as a part of the basic life cycle analysis.

One aspect of improved LCA that we have not had time to discuss in detail is the need for improved data. In particular, models representing real causal relationships can only be developed if data can be made available on all aspects of those relationships. Neitner existing data systems nor those under development--as we understand them--provide an adequate basis for developing estimating relationships and models at this level.

CHART 13

In summary, we have observed that present procedures and techniques for making LCC estimates can lead to decisions that have effects opposite to what the decisionmaker is seeking. Opportunities to reduce overall costs may be missed. R&D funds may be invested without achieving an expected O&S cost reduction, thereby increasing LCC.

This situation is partly due to limitations in existing models and the data available for use with them. Even with improved models, however, reliable estimates would be dependent on the use of good analytical procedures. The procedures used in some analyses, as exemplified by our case studies, are inconsistent and undisciplined enough to contribute to the overall confusion. The establishment of a uniform set of procedures for conducting and presenting the results of life cycle analyses should help in two ways. It would compensate for some of the shortcomings of current models and data, and it would provide a useful basis for the development of improved estimating techniques in the future.

Chart 13

SUMMARY

- MAJOR CONSEQUENCE IS RISK OF INCORRECT DECISIONS
  - MISS OPPORTUNITIES TO REDUCE LCC
  - WASTE R AND D INVESTMENT DOLLARS
- PARTLY DUE TO MODELS AND DATA
- ALSO DUE TO COST ANALYSIS PROCEDURES
  - PRESENT PROCEDURES CONTRIBUTE TO CONFUSION
  - PROPER PROCEDURES COULD OFFSET MANY SHORTCOMINGS OF MODELS

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